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High Temperature Application of Retrievable MWD Systems

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ABSTRACT

MWD systems are currently used to monitor the direction of wellbores. MWD systems with higher temperature capabilities are required to meet the needs of deep and geothermal drilling.

A technique has been developed for geothermal drilling that allows a fully retrievable MWD system (Slim 1*) to be used in wells with formation temperatures in excess of 350°C. This operational technique involves use of the MWD system in combination with operational procedures adapted to cope with the need for continuous directional control while drilling. Descriptions of the drilling environment are given in areas of Japan where high temperature drilling is performed. Possible future requirements are reviewed. The MWD system is described giving current technical specifications and capabilities. The operational method for utilizing the MWD is detailed. A summary of successful applications is discussed and specific case studies given. The efficiency of using the technique is reviewed.

INTRODUCTION

MWD systems were introduced to the drilling industry in the early 1980's to improve drilling efficiency and perform formation evaluation[1]. Since that time, systems have been developed with multiple capabilities that include drilling mechanics, with use of downhole weight-on-bit and torque, and formation evaluation for real-time logging. The primary economic benefit has come from the use of MWD as a real-time steering and directional tool which provides accurate positional information of the well bore while drilling. Real-time knowledge of the direction and inclination of the well path minimizes rig time for guiding the well. This results in significant cost savings.

Historically, geothermal operators have not used MWD due to temperature limitations associated with non-retrievable MWD systems[2]. The normal operating specifications for these systems is 120°C to 150°C. A fully retrievable MWD (Slim 1) has been developed[3]. With a combination of a retrievable MWD system with steerable motors, and the use of mud cooling techniques, depths of more than 2,000 m have been reached in 12 ¼ in. holes, in formations exceeding 350°C.

For the past two years this MWD technique has been used successfully in geothermal applications in Japan. This paper concentrates on the MWD system and technique which allows use at these temperatures. Wells have been drilled using MWD successfully in 5 of the 10 major geothermal areas in Japan. **Figure 1.**

Current and future temperature requirements

Normally, geothermal fluids exist in fractured zones and geothermal fields are found in mountainous terrain and/or national parks. Rig positioning is a significant problem for operators and several wells are usually drilled from the same site location. This results in a majority of wells being deviated.

Currently, formations with temperatures in the range of 200°C to 400°C are required for commercial production of steam in geothermal operations. Historically, wells had been deviated at shallow depths where the formation temperatures are compatible with temperature specifications of conventional technology (ie. < 150°C). This meant the use of either a single shot, steering tool, or non-retrievable MWD. As the need for higher temperature fluids has increased, so has the requirement for drilling in deeper and hotter reservoirs.

In geothermal fields the well temperature increases very rapidly in the first 500 m. An example of a drilling program from Well-20 of the Kakkonda field near Morioka city in Japan is as follows[4]:

Hole Size	Casing Size	Mean Depth Set	Avgerage formation temperatures
34 in.	26 in.	50 m	100°C
24 in.	18 ⅝ in.	500 m	210°C
17 ½ in.	13 ⅜ in.	1200 m	240°C
12 ¼ in.	9 ⅝ in.	2200 m	310°C
8 ½ in.	7 in. slotted liner	3000 m	350°C

These formation temperatures are in excess of the ± 150°C temperature limitations for current MWD systems (although at the time of writing this paper a commercial non-retrievable system is now available with a 175°C rating)[5].

Deviation generally occurs in the 17 ½ in. hole and 12 ¼ in. hole sections. As long as the depth is not too great, single shots with heat shields can be used to deviate the wells successfully. Steering tools have also been used. With single shot and steering tools, directional control is difficult for depths much over 700 m. Rig costs have also significantly increased over the past ten years. This makes the time to deviate the well important. Advantages and limitations are summarized below.

	Advantages	Limitations
Single Shot	Inexpensive	Difficult to orient BHA at deep depths. Extremely time consuming.
Steering Tool	High Temperature Rating (200°C)	Difficult to handle (cable), time consuming and cannot cool tool with circulation. Reliability limited.
MWD non-retrievable	High Reliability (175°C)	Must run in the hole before mud is cooled. Cannot retrieve the tool for replacement if the hole overheats.

Slim 1 can be used despite the high temperatures involved.

Figure 2 shows temperature logs which were completed after the drilling of Well-20 at Kakkonda. This is very unique in that multiple temperature surveys were done, allowing an unusually rare view of a geothermal well temperature profile. The Well-20 formation temperature is estimated from the log data of Well-18. Well-20 has only logged data after 9 days standing time and the temperature was still increasing. Well-18 data was taken after 4 months standing time from the same pad in a slim hole. The two well trajectories are close and Well-18 data is considered representative of the true formation temperature. Despite formation temperatures above 300°C (curve J in Figure 2), Bottomhole Circulating Temperature (BHCT) as measured by the MWD remained less than 100°C in the 12 ¼ in. hole section (curve C). The current temperature limitation of the Slim 1 is 150°C. This is mostly a function of the lithium batteries used to power the tool. However, electrical and mechanical components also begin to exceed their design limitations at this temperature.

One other consideration in drilling with an MWD system is the downhole motor. Commercial materials used to make and bond the stator fail at BHCT's in the range of ±150°C. Downhole motor performance is limited in terms of temperature resistance, when compared to that of the MWD. This is a result of different operating conditions and despite similar temperature ratings, the downhole motor must be run on the drill string and cannot be put in the hole after the hole has been cooled[7].

Future MWD equipment will be required with ratings in the range of 200°C as shown in curves E to G of Figure 2 for depths where the formation temperature is known to exceed 300°C and hole diameter is small (typically 8 ½ in. and smaller).

Retrievable MWD systems applied in environments over 150°C

EXISTING MWD SYSTEM

The Slim 1 tool has a length of 28.4 ft and can be customized to fit different non-magnetic drill collar lengths using extensions. Below the standard non-magnetic drill collar is a Universal Bottom Hole Orienting (UBHO) sub for orienting and landing the tool. The maximum OD of the tool is 1 ¾ in. and it can be used in drill collars from 3 ½ in. OD and larger. Figure 3.

The tool was specifically designed to be retrievable using conventional 0.092 in. slick line and overshot. Originally this was to minimize lost-in-hole costs. In the case of high temperature operation the tool can be placed in the drill-string after hole cooling and retrieved prior to pulling the drillstring out of the hole.

Power is supplied by lithium batteries. The lithium batteries comprise one of the prime safety concerns with high temperature operation. Lithium metal (Li) will spontaneously ignite (explode) at temperatures exceeding 170°C. All precautions are taken at the well site to ensure the tool and the batteries never reach this temperature.

An MWD positive pulse transmission mode is used to send the data to the surface. Operating specifications are summarized below.

Operating Ranges:	
Temperature	-40°C to + 150°C
Downhole Pressure	15,000 psi
Flow Range	80 to 1,200 gal/min
Mud Type	Unlimited
Solids Content	< 2.5%
Parameter Accuracy	
Drift	± 0.1°
Azimuth	± 1.0°
Tool Face	± 1.0° rounded to 3°
Temperature	± 0.1°C

Downhole temperature of the drilling fluid inside the drill-string is sent to the surface by the tool upon command.

OPERATIONAL TECHNIQUE

The MWD tool is used in conjunction with a steerable motor, or during rotary drilling, to allow trajectory control during geothermal operations. The bottom hole assembly (BHA) is made up as in normal drilling operations with the UBHO sleeve being adjusted to match the bent angle of the motor. After completion of the BHA, the assembly is run in the hole. From this point hot use of the Slim 1 deviates from standard directional drilling practices.

1) Geothermal Mud Cooling System

Full utilization of mud cooling systems as developed by geothermal operating companies must be employed. Figure 4 shows such a system as used in Kakkonda. Mud in and out temperatures are within ± 20°C and less than 100°C when the system is fully in use up to depths of 2,700 m (curves A and B, Figure 2). The indicated differences from conventional systems include:

- two mud cooling towers
- an extra mud cooling pit
- complete solids control equipment

2) Intermediate Staging Circulation

Generally, if the well temperature is less than ± 200°C, the MWD is run in the hole within the BHA. The BHA is then "staged in". At the casing shoe, circulation is broken and a minimum of one and a half complete hole circulations are made. This allows the hole, the tool and the motor to be cooled. Depending on the depth, this might be repeated to displace the latent heat but in general is done only once during the trip in.

3) Running the tool in on slick line

If the well temperature is critical, the BHA is run into the hole as quickly as possible. The MWD is not in the BHA at this time. Staging is necessary to cool the motor. Tripping in time is minimized in order to minimize stator damage to the motor and damage to the bit seals. As soon as the BHA is on the bottom, circulation is begun and continued until the well temperature stabilizes.

The tool is then run in the hole on a hydraulic releasing overshot. This differs from a normal J-slot type overshot in that the hydraulic releasing overshot has a preset release time. This time is determined by the operating engineers at the well site to ensure the tool is not pre-released while running in the hole, and when retrieving the tool, that the tool is firmly latched for retrieval.

4) Survey temperature immediately upon reaching bottom.

Once the tool is in place, a survey is taken for directional information and to ensure that the bottomhole temperature is within operational limits.

Extremely close cooperation between the rig personnel and the MWD operating engineers is mandatory, particularly regarding wireline running of the tool in and out of the hole. The BHA design must also ensure that the minimum ID of any component is not less than that which will pass the OD of the Slim 1 tool freely within the drillstring.

CURRENT LIMITATIONS

The system described has the following limitations:

- The Slim 1 is rated to 150°C. The temperature of the lithium batteries must never exceed 170°C.
- An efficient mud cooling system is required.
- Downhole motors have stator limitations also in the 150°C range. The stator rubbers begin to vulcanize causing the stators to chunk and the motors to become unusable. As pointed out earlier, MWD and motors have different running conditions.
- If the MWD cannot be retrieved and circulation capability is lost, a high cost will be incurred to replace the tool.
- Most geothermal wells have a high incidence of lost circulation. The MWD system, although somewhat tolerant, cannot support high LCM concentrations, although the tool may be retrieved by wireline to pump higher concentrations.

Operational Examples In Geothermal Drilling

OVERVIEW OF WORK IN JAPAN

Ten wells in five different geothermal areas have been successfully drilled with no damage to the Slim 1 MWD system due to temperature. Maximum formation temperatures of 350°C have been recorded. Table 1 summarizes usage and area.

CASE HISTORY EXAMPLE: KAKKONDA FIELD, JAPAN

Table 2 is a summary of the first continuous use of retrievable MWD in a geothermal application done in 1992. Well-20 is a production well in the Kakkonda geothermal field. The Kakkonda field has been producing steam for geothermal power generation since 1978.

Slim 1 was employed after 2 correction runs were attempted with single shots, but the tool face orientations could not be properly controlled due to the reactive torque of the motor at the depth of correction. A total of 27 runs were made with Slim 1 for over 300 hours of downhole circulating time while drilling the well. During the entire operating time with MWD the formation temperature was greater than 150°C.

IMPROVED EFFICIENCY

After two years of operation, the benefits of using retrievable MWD tools can now be easily demonstrated. Figures 5 and 6 show the planned drilling curves vs. actual for three recently drilled wells in Kyushu, Japan. In all cases a steerable system was employed.

The Takigami Geothermal Field is located in Oita prefecture on the island of Kyushu. Slim 1 was used to improve performance in the 12 ¼ in. hole section where the kickoff was usually made. Because of reservoir constraints the target was extremely tight and consisted of a 25 m radius cylinder starting at 1754 m TVD and extending for 150 m with a direction of due south with 39° inclination.

As can be seen by the drilling curve (Figure 5) the tophole section drilled unusually slow and the 17 ½ in. hole section ended 7 days behind the drilling curve. Using Slim 1 combined with steerable motors, all 7 days were made up and the well was put back on plan. The well was drilled within the target and with no operational problems.

Another operating company which was working in Kyushu also gained time improvements for a kickoff and hold in the 17 ½ in. hole section for a well at the Fushime Field in Kagoshima prefecture. This is demonstrated in Figure 6. In the past, drilling of the 17 ½ in. hole was preceded by a 12 ¼ in. pilot hole to assist in maintaining directional control and to allow wireline logging.

It was decided that the 12 ¼ in. hole was not required and the subsequent 17 ½ in. hole was drilled with a retrievable MWD tool. The drilling plan was subsequently revised. Ten days after spud (as compared to 23 days in past wells) the 13 ⅜ in. casing point was reached. After review of the first well's drilling time it was decided to use Slim 1 again. The second well showed a further improvement of one day. There were no equipment problems of any kind. A net improvement of 9 days (including lost circulation time) was achieved over previous drilling results in this field.

Conclusions

1) Use of MWD in environments where the formation temperature is greater than 150°C is viable. Requirements include:

- An efficient Mud Cooling and Solids Control System.
- A fully retrievable MWD system.
- Correct application of operating procedure.

2) Improved drilling efficiency can be achieved by using MWD combined with steerable motors in high temperature environments.

3) Temperature limitations still exist in today's technology. Downhole circulating temperatures of no more than 150°C are required. Future equipment will be required with capabilities in the 175°C to 200°C range.

NOMENCLATURE:

* Mark of Schlumberger

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Table 1

Slim 1 Usage in High Formation Temperature in Japan

Prefecture	Field	Period	Hole Size	Depth Interval	No. Runs	Max. Inc.	Formation Temperature
Akita	Uenotai	July 1992	12 1/4 in.	340 m - 871 m	6	21°	250°C
Iwate	Kakkonda	August 1992	12 1/4 in.	1,531 m - 2,245 m	27	24°	350°C
Akita	Uenotai	October 1992	12 1/4 in.	317 m - 652 m	5	19°	230°C
Iwate	Kakkonda	May 1993	12 1/4 in.	1,506 m - 1,767 m	17	9°	300°C
Akita	Sumikawa	June 1993	8 1/2 in.	935 m - 1,101 m	6	21°	300°C
Iwate	Kakkonda	September 1993	8 1/2 in.	1,634 m - 1,854 m	4	25°	320°C
Oita	Takigami	October 1993	12 1/4 in.	1,050 m - 1,771 m	5	37°	230°C
Kagoshima	Fushime	December 1993	17 1/2 in.	350 m - 806 m	1	20°	240°C
Kagoshima	Fushime	March 1994	17 1/2 in.	350 m - 713 m	1	19°	200°C
Iwate	Kakkonda	May 1994	17 1/2 in.	1,298 m - 1,505 m	6	3°	270°C

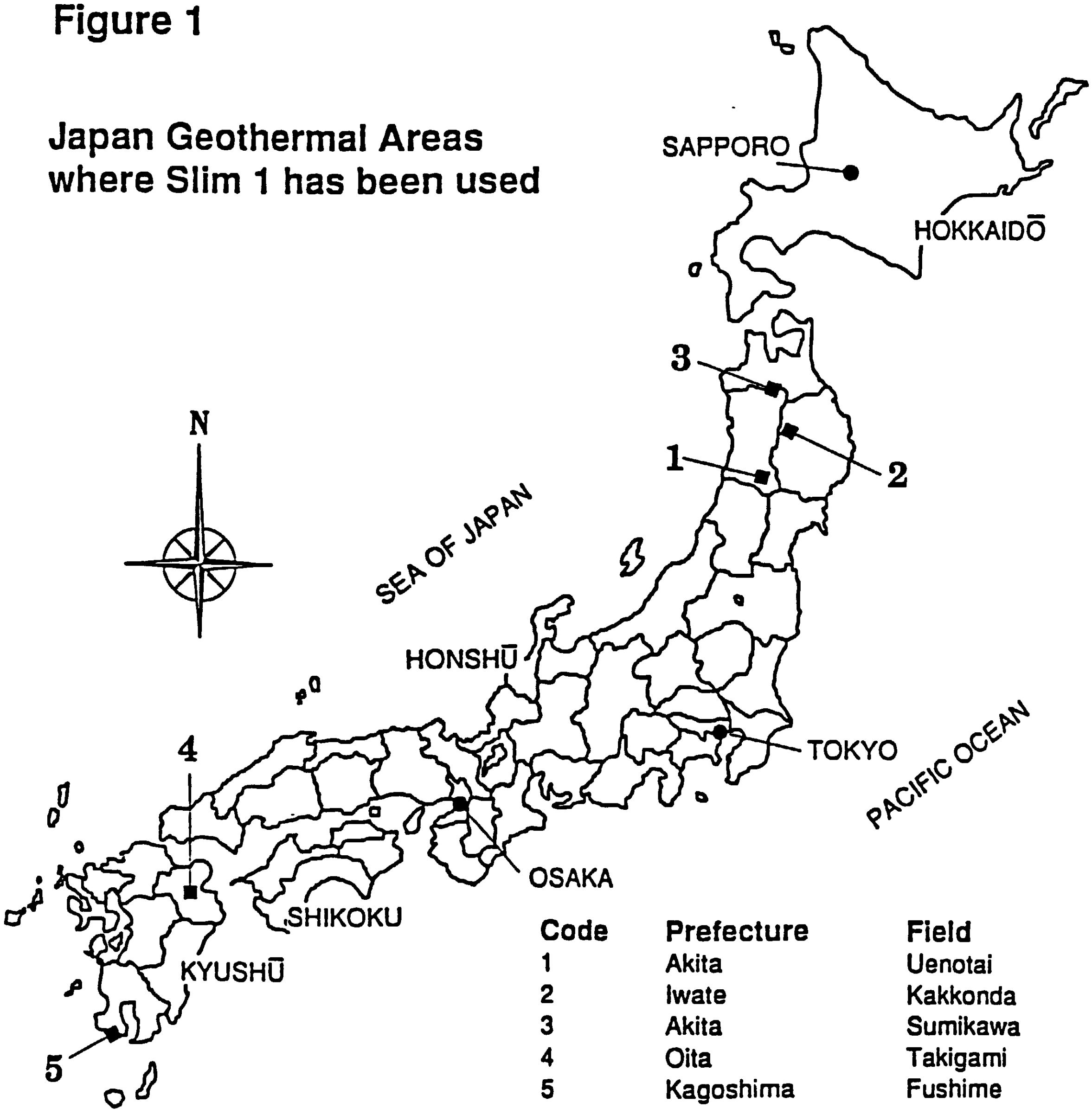
Table 2

MWD (Slim 1) performance summary of Well - 20 at Kakkonda

Hole size	MWD Run No.	Downhole Motor Run No.	Drilled Interval (m) From	Drilled Interval (m) To	Slim 1 Hours Run (h)	BHCT (°C)	TOOL NO.	Results	Down Time (h)	Remarks
	1	3	1531.00	1548.50	2.7	65	O85	good	0	
	2				27	62	O93	good	0	
	3	4	1556.00	1569.40	26	64	O93	good	0	
	4	5	1530.00	1539.90	18	64	O93	no good	0.75	Battery wire parted
	5	6	1539.90	1542.70	13	65	O63	good	0	
	6				2	65	O72	no good	6	Dropping the tool resulted in: – Parted battery wire – Damaged Pulser Restrictor
	7				13	64	O63	good	0	
	8	7	1538.00	1549.00	0	N/A	O63	no good	1.5	Battery wire parted Battery pico Fuses blown
	9	8	1549.00	1565.50	10	65	O72	no good	0	Intermittent tool jamming caused battery pico fuse to blow
	10				3.5	65	O63	no good	1.5	As above
12 1/4 in.	11				7.5	65	O93	good	0	
	12	9	1575.00	1603.50	24	65	O63	good	0	
	13	Rotary	1603.50	1616.00	18.5	68	O63	good	0	
	14	Rotary	1616.00	1624.00	14.5	77	O93	good	0	
	15	Multi shot	1536.00	1611.00	1.5	77	O93	good	0	
	16	Rotary	1685.50	1803.00	35	78	O93	good	0	
	17				34	82	O72	good	0	Change tool to put in new battery
	18				7	79	O72	good	0	
	19	10	1810.40	1838.40	34	82	O72	good	0	
	20	11	2107.50	2129.00	6	82	O72	no good	3	Conductor wire insulation failed
	21				8	N/A	O97	no good	0	Tool free fall to bottom causing mainshaft to bend and pulser to flood
	22				20	82	O72	good	0	
	23	12	2191.60	2198.50	8	82	O93	good	0	
	24	13	2198.50	2211.20	10.3	82	O72	good	0	
8 1/2 in.	25	14	2245.00	-	0.3	166	O72	no good	1.5	
	26				1.5	150	O93	no good	1.5	High bottom hole circulating temperatures caused tool failures
	27	15	2245.00	-	0.3	166	O72	no good	1.5	

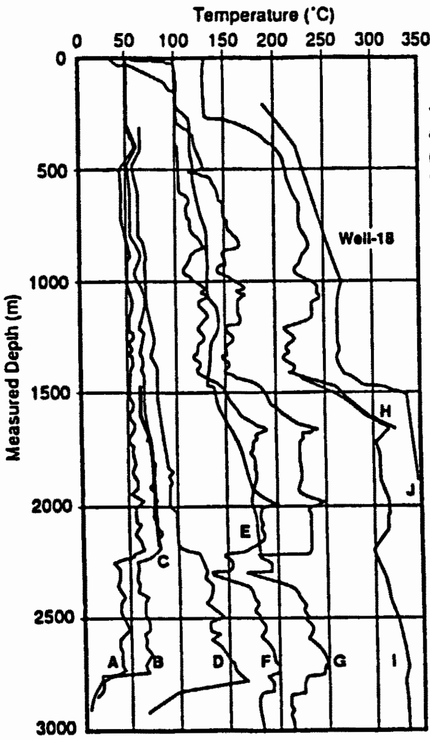
Figure 1

Japan Geothermal Areas where Slim 1 has been used



Code	Prefecture	Field
1	Akita	Uenotai
2	Iwate	Kakkonda
3	Akita	Sumikawa
4	Oita	Takigami
5	Kagoshima	Fushime

Figure 2



Temperature distribution curves of Well-20 and Well-18 at Kakkonda

(Saito, 1993)[4]

Well-20

A, B: Drilling fluid temperature measured at suction tank (A) and flow line (B)

C: Bottom hole circulation temperature measured with MWD (Slim 1)

D: The temperature inside the non-magnetic drill collar about 15 m above the bit within 1 hour after circulation ceased. Recorded with thermometers.

E: The temperature log data at 13 3/8 in. casing depth after standing time of 12 hours.

F, G, H-I: Temperature log data at TD after standing time 24, 49 hours and nine days. From 2,784 m well was drilled with lost circulation.

Well-18

J: Temperature log data after standing time 4 months

E, F, G, and H were recorded with Platinum resistance thermometers

I and J were recorded with Kuster thermometers

Figure 3

Slim 1 Downhole Tool
Positioned In Standard Nonmagnetic Drill Collar

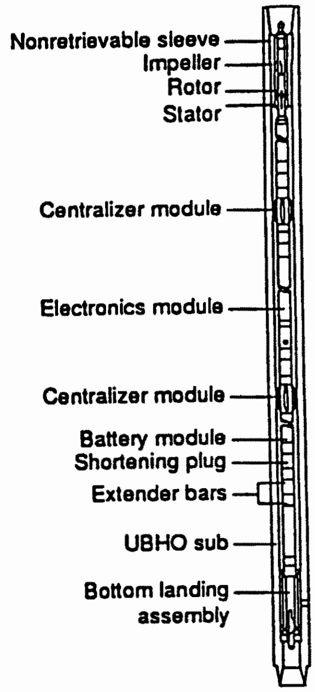
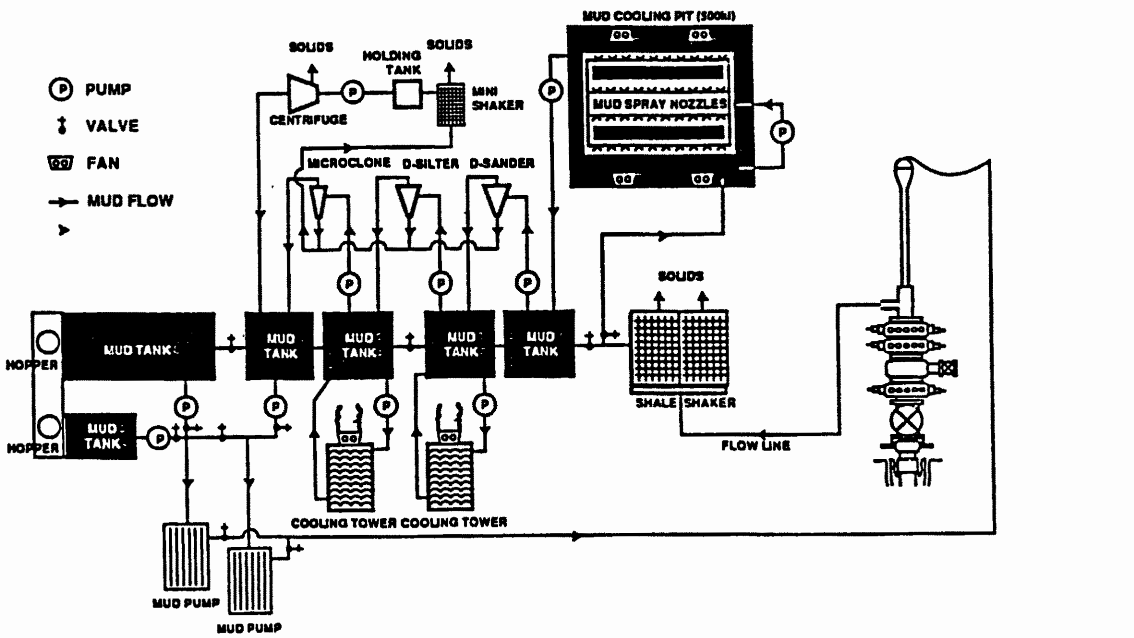


Figure 4



Schematic of mud cooling and solid control system used in Kakkonda Field in Japan.
(Saito, 1993) [6]

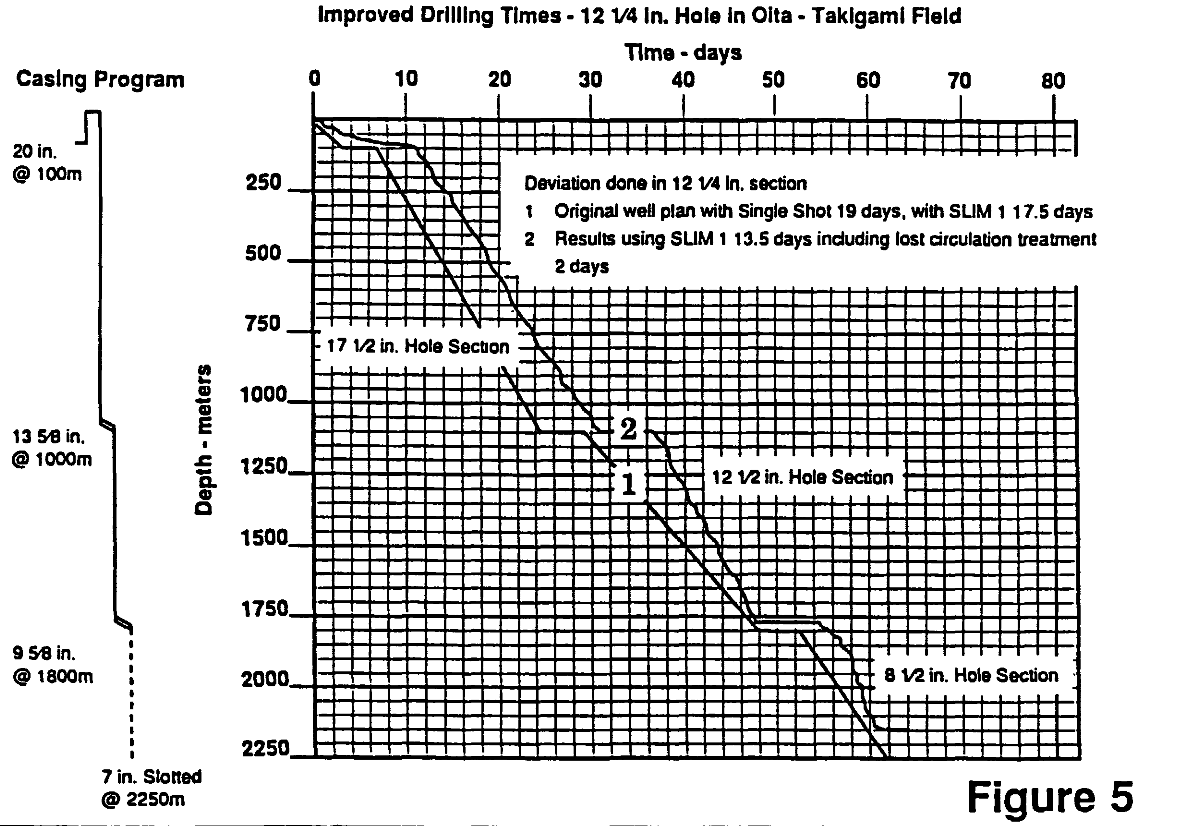


Figure 5

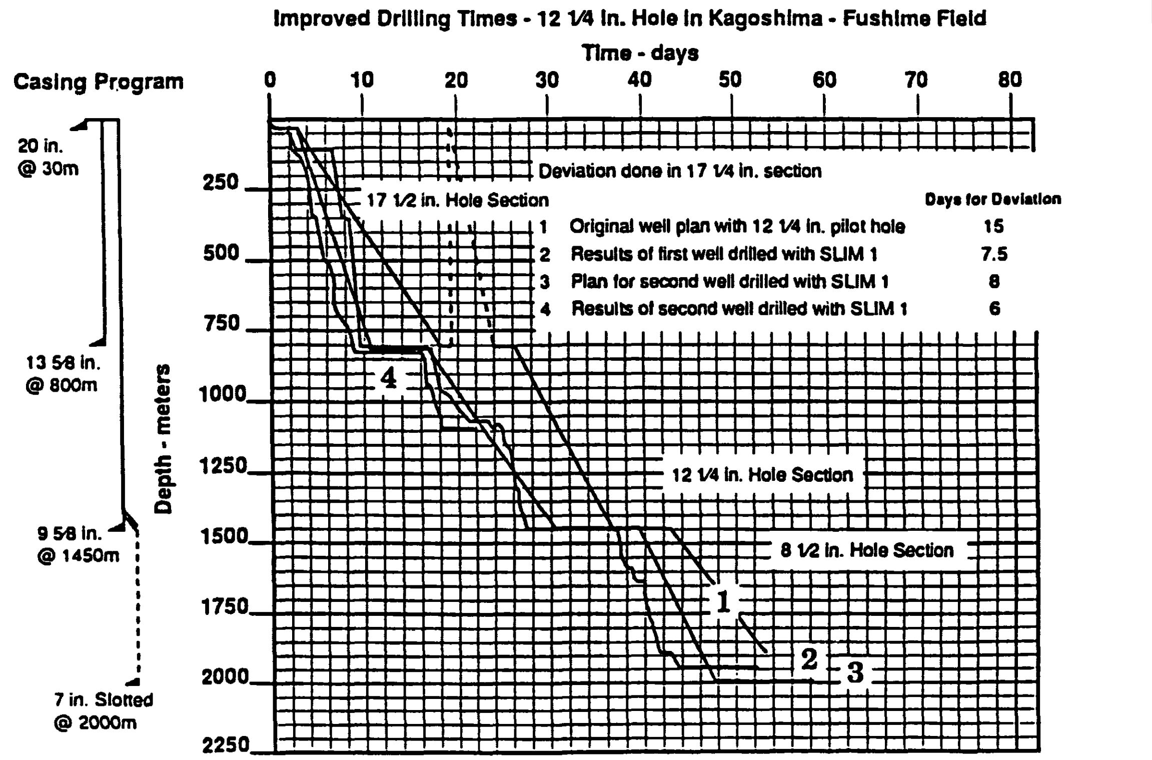


Figure 6